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Fall ARSRP Research Symposium For
1 - 3 December, 1993
La Jolla, CA

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DTIC	TAB	<input type="checkbox"/>
Unannounced		<input type="checkbox"/>
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Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
La Jolla, CA

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ACOUSTIC REVERBERATION AT SELECTED SITES IN THE MID-ATLANTIC RIDGE REGION¹

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Sound scattering from rough surfaces is a very complex phenomenon. Although it has been studied extensively, a full understanding of a three-dimensional scattering function is still lacking. In 1989 the Office of Naval Research (ONR) established the Acoustic Reverberation Special Research Program (ARSRP) whose purpose is to improve this understanding for scattering from the sea surface and the seafloor.

As a part of the bottom scattering effort of the ARSRP, researchers from NRL, several universities, and oceanographic institutions have engaged in experimental and theoretical studies of acoustic reverberation in a region of the Mid-Atlantic Ridge (MAR) near 46°W, 26°N, called the ONR Atlantic Natural Laboratory. Extensive, high-quality, bottom reverberation data were collected in two cruises to the area: ARSRP'91 (also called the Acoustic Reconnaissance Cruise) in the summer of 1991 and ARSRP'93 in the summer of 1993. In these experiments both distant and short-range reverberation data were taken at frequencies around 230 Hz. The RV *Cory Chouest* worked alone in ARSRP'91. In ARSRP'93 the *Cory* worked with Wood Hole's RV *Knorr* and the NATO/SACLANT ship RV *Alliance*. Here we discuss the character of the short-range (7-18 km) reverberation data collected by the *Cory* near a sedimented pond, designated as Site A by the ARSRP.

Geomorphology: To support analyses of the acoustic data, two geological and geophysical (G&G) cruises were also conducted in the Atlantic Natural Laboratory. Figure 1 shows the geomorphology in a portion of the survey area (65x50nm) at a resolution of 200m. In this area there are three distinct morphological provinces. In the vicinity of Site A, the morphology is typical of "outside corner" crust [3] (Karson and Dick, 1983). This crust is formed at a mid-ocean ridge segment adjacent to a passive transform fault. The relief is subdued and is dominated by orthogonal, steeply dipping normal faults which face towards the valleys and are aligned parallel and perpendicular to the ridge. The rock type is primarily basalt. This structure persists through most of the southern half and the northernmost quarter of Figure 1. Regions C, C', and C'' are typical of "inside corner" crust which formed at a ridge adjacent to an active transform

¹ This is a pre-print from the 1994 NRL Review.

fault. The relief is dominated by fault scarps, with variable orientation, but primarily oblique to the ridge axis. The exposed-rock types are more plutonic than volcanic representative of deeper crustal levels in 'normal' crust. Between the inside and outside corners is a flat sedimented valley (labelled V), running WNW to ESE, about 4400m deep. Broad-scale features in the acoustics data are caused by the orthogonal ridges and fault scarps where they protrude into the insonifying beam. It is not yet clear however, whether the fine-scale reverberation is different for inside and outside corners, but the sedimented valleys appear to produce weaker scatter. Shown in the insert for Figure 1 are three ping positions (44, 76 and 77) and the ship headings for reference in later discussions of the scattering at Site A.

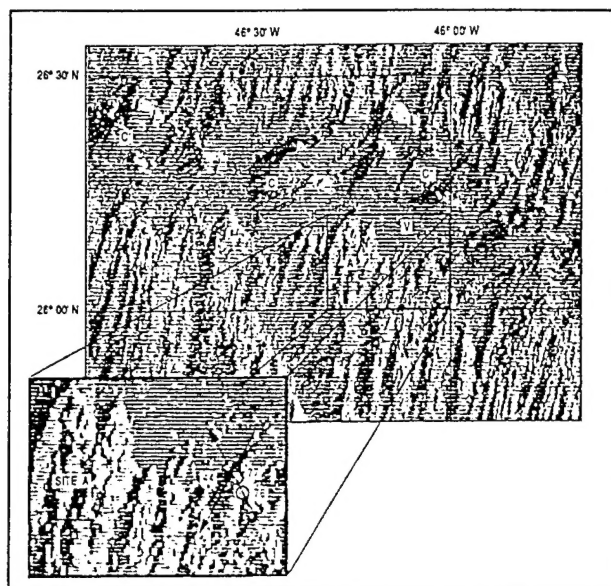


Figure 1: Geomorphology for a 3000 nm² region of near the MAR as it would appear if lit by a rising Sun. Insert shows Site A and ping positions discussed. (Data provided by B. Tucholke, WHOI.)

Figure 2 shows the one-way transmission loss to the region of interest on the seafloor. The source, a ten-element vertical line array, was steered nine degrees down from horizontal to insonify the seafloor at ranges from 7 to 18 km. This downward steering ensures a reduction of the energy reflected from the sea surface, and greatly simplifies the transmission-loss character on the bottom. The waveform of the transmitted signal was a linear FM about 55 Hz wide centered at 230 Hz.

Reverberation: The effects of the ridges at Site A are clearly seen in the scattering diagrams of Figure 3. Each of the lines in the three displays in the figure is the time evolution of the reverberation intensity along a beam at the angle given on the vertical scale as measured from the head of the horizontal receiving array (track of the ship). (Reverberation intensity is the matched filtered output in each beam, expressed in dB.) For all three pings the ship is at about the same position, forming a small triangle about 1.3 km on a side, so the times of echos from individual points along the ridges are about the same. In the diagrams reverberation from the ridges occurs at about 15 to 30 sec. For pings 76 and 77 the shapes should also be about the same since the receiving array has the same

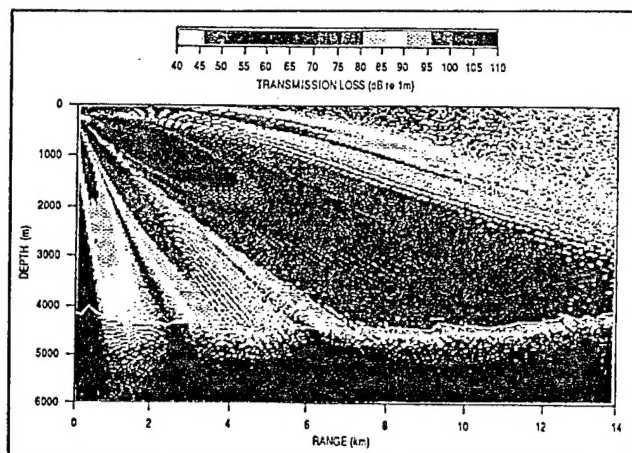


Figure 2: Transmission loss predicted by UMPE for 9 degrees downward steering of source array into Site A. (UMPE calculations provided by K. Smith, Scripps.)

orientation. The heading of the receiving array for ping 44 was different from the heading for pings 76 and 77, so the angular positions and orientations of the ridges appear differently in its scatter diagram.

A detailed analysis of these scattering patterns shows that they are consistent with these expectations. One should be aware, however, that because the receiver is a horizontal line array, there is a left/right ambiguity; that is, one cannot tell from which side of the array the echos are coming. For the track for ping 44, Site A is in the right forward half of the angles around the array (i.e., 5° to 90°); the ambiguous region is to the left at equivalent angles. Site A is in the left forward half of the array for pings 76 and 77; the ambiguous region is to the right of the array. The ambiguous regions for ping 44 and for the set 76 and 77 are, therefore, not the same and some uncorrelated scattering can be expected. Detailed analysis shows, however, that the dominant scatter for all three pings is coming from Site A and the ambiguous sides are contributing very little scatter in these cases.

The Bistatic Scattering Strength Model: The bistatic scattering strength model (BISSM) [1,2], which predicts reverberation using fine-scale morphology such as is available for the ARSRP experiments, was run for several pings at Site A. The results for ping 77 are shown in Figure 4. BISSM-predicted reverberation is mapped onto the seafloor at its origination points. Bright yellow represents regions of the seafloor that are "lit up" by the acoustic energy. The bright spot in the center is directly under the ship at ping 77 and the circular patterns are indicative of the directionality of the acoustic energy for the vertical line array source steered down at 9 degrees. The bright region to the NNE is the side of a seamount (C") of the inside corner character (C-type) and just beyond is the dark shadow on its far side. Directly under the ship and to the NW/ESE is a flat, sedimented area (V-type) of low backscatter. A little further around counter-clockwise, to the West and WSW, is a series of ridges showing bright faces on their forward slopes followed by dark shadows on

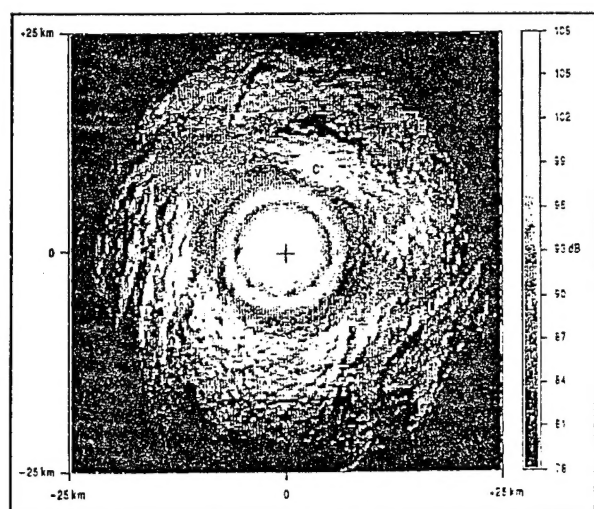


Figure 4: Reverberation levels (for each 200x200m patch) predicted by BISSM and mapped onto the seafloor.

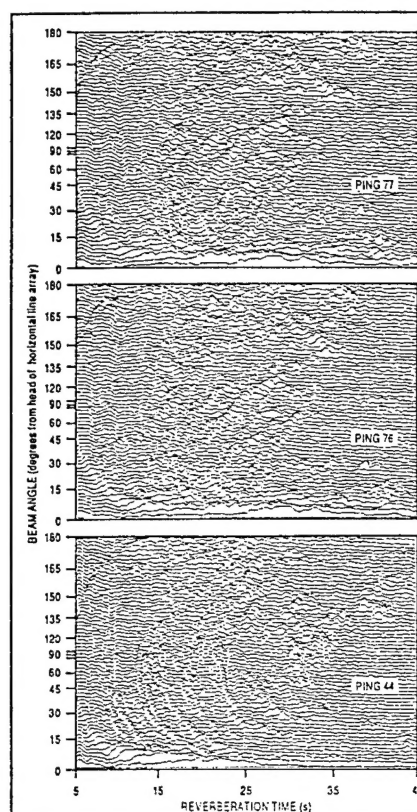


Figure 3: Reverberation evolution for pings 44, 76, and 77. Scattering at Site A seen in region from 15 to 30 seconds and 5 to 90 degrees.

their far slopes. These are the ridges at Site A. The darkness all around the diagram beyond the illuminated area is where the acoustic rays bend upward from the bottom and leave the rest of the bottom in a shadow zone. Also, when the data displayed in Figure 4 is mapped into beam/time diagrams (like Figure 3), there is a strong match between predicted and measured scatter. Quantitatively, BISSM has been validated in these cases by the adjustment of an empirical coefficient to a value of 17 dB (generally accepted by the ARSRP).

Summary: Seafloor morphology is clearly a controlling factor in the broad-scale scattering observed in a rugged region like the MAR. Strong contrast was found between scattering from deeply sedimented areas and from rugged, exposed-rock ridges. Less pronounced differences were found between exposed-rock regions of known geological differences, e.g., inside versus outside corner. Prominent features were found to be repeatable for pings from nearby positions and between cruises, suggesting that variations in the transmission loss is not the cause for the features observed. It is suggested here that the dominant effects being observed are the effects of the modulation of the grazing angle dependence of scattering by the variation of the slopes of the scattering surfaces. It is likely that the degree and form of surfacial roughness (i.e., fine-scale morphology or texture) is also a factor in defining the character of the echos.

Acknowledgments: We wish to recognize the contributions of the following scientists: Dr. Moshen Badicy, Program Manager, ARSRP, Dr. Brian Tucholke, collecting and analyzing and providing the geomorphological information use here, Dr. Kevin Smith for UMPE (University of Miami Parabolic Equation) calculations used in Figure 2, and Dr. Jorge Novarini and Mr. E.J. Yoerger for assistance in the development of BISSM.

[Sponsored by ONR]

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REPORT DOCUMENTATION PAGEForm Approved
OBM No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 1993	3. REPORT TYPE AND DATES COVERED Proceedings	
4. TITLE AND SUBTITLE Acoustic Reverberation at Selected Sites in the Mid-Atlantic Ridge Region			5. FUNDING NUMBERS Job Order No. 71520604 Program Element No. 0601153N Project No. 3204 Task No. 040 Accession No. DN251004	
6. AUTHOR(S) Jerald W. Caruthers, J. Robert Fricke ¹ , and Ralph A. Stephen ²				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Center for Environmental Acoustics Stennis Space Center, MS 39529-5004			8. PERFORMING ORGANIZATION REPORT NUMBER NRL/PP/7175--93-0066	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research 800 N. Quincy Street Arlington, VA 22217-5000			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Fall ARSRP Research Symposium 1-3 December, 1993 La Jolla, CA ¹ Massachusetts Institute of Technology ² Woods Hole Oceanographic Institution				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Sound scattering from rough surfaces is a very complex phenomenon. Although it has been studied extensively, a full understanding of a three-dimensional scattering function is still lacking. In 1989 the Office of Naval Research (ONR) established the Acoustic Reverberation Special Research Program (ARSRP) whose purpose is to improve this understanding for scattering from the sea surface and the seafloor.				
14. SUBJECT TERMS bottom scattering, reverberation			15. NUMBER OF PAGES 5	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR	